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Rubber-Tired Equipment for Farm Machinery

G. W. McCuen and E. A. Silver

OHIO
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RUBBER-TIRED EQUIPMENT FOR FARM MACHINERY

G. W. McCUEN AND E. A. SILVER

THE FARM TRACTOR

Rubber tires for tractors are not entirely a new development. For several years tractors have been equipped with rubber tires but these were mostly for industrial purposes. The tires were generally of the solid type and were not deemed practical for farm use because of their low tractive efficiency in soft or wet and sticky soils.

During the fall of 1931 and early in 1932 a new type of tire appeared for use on the farm tractor. This tire was of the pneumatic type and of larger proportions than anything which had been previously put to farm use. It had its origin largely from the low-pressure balloon tire adapted to aeroplane landing gears.

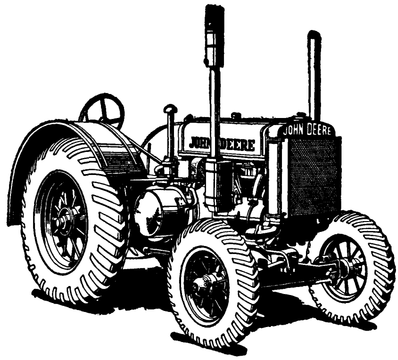


Fig. 1.—Tractor mounted on low-pressure pneumatic tires

The rear wheel tires carry approximately 12 pounds of air pressure and the front wheel tires approximately 16 pounds. Because of the low air pressure these tires have been rightfully termed "low-pressure pneumatic tires".

During the fall of 1932, the Agricultural Engineering Department of the Ohio Agricultural Experiment Station conducted a series of tests to determine:

1. The rolling resistance of the tractor when equipped with steel wheels and lugs and with low-pressure pneumatic tires.
2. The fuel consumption of the tractor when equipped with steel wheels and lugs and with low-pressure pneumatic tires.
3. The draw-bar pull of the tractor when equipped with steel wheels and lugs and with low-pressure pneumatic tires.

The work was done on the Ohio State University farm where the soil is typical of most soils in Franklin County, ranging from a heavy jack-wax to a brown silt loam. The field was covered with a heavy growth of timothy interspersed with numerous alfalfa plants. The subsoil was extremely dry and the surface wet to a depth of about 3 or 4 inches due to a previous 2-day rain. Another series of tests was run on the plowed ground.

A four-wheel, conventional type tractor was used for this work. The two types of wheels—steel and rubber tired—were interchangeable on the same axle. The static or dead weights of the tractor when equipped with both types of wheels are as follows:

	Front	Rear
	Lb.	*Lb.*
Steel wheels with 6-inch spade lugs	1500	3000
Low-pressure rubber tires with added weights on rear wheels	1700	3340

The size of the rubber tires was: Rear, 11.25 x 24; front, 6.00 x 16. Four hundred thirty-four pounds were added to each rear wheel when equipped with rubber tires so as to obtain maximum traction. A gulley integrating traction dynamometer was hooked between the implements and the tractor to determine the draw-bar pull. The two-bottom 14-inch plow, subsoiler, disks, and harrows were the implements used.

ROLLING RESISTANCE OF TRACTOR

This work was conducted for the purpose of determining the rolling resistance of the tractor when equipped with low-pressure rubber tires and steel wheels with lugs. The significance of this factor lies in the fact that if the tractor has a low rolling resistance it will require less power to move its own weight over the ground. More power will, therefore, be available at the drawbar of the tractor if other factors are considered equal. This will result in economy of fuel consumption as indicated under a later discussion of this phase of the problem.

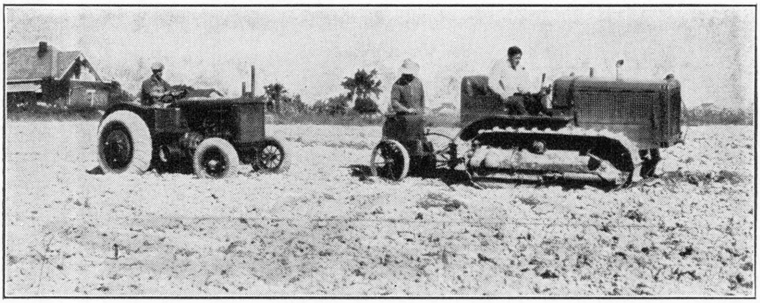


Fig. 2.—Testing for rolling resistance on plowed ground

To determine the rolling resistance of the tractor, the dynamometer was placed between it and another tractor which acted as the prime mover. The dynamometer recorded the pull (in pounds) required to move the tractor over the ground, the time, and the distance traveled. The tractor was pulled over timothy sod and over freshly plowed ground at various speeds or rates of travel. An interval of 60 seconds was used as a standard length of time for a test. A run was made in both directions for each test, in order to compensate for any grades which might have been encountered on the test course.

It is evident from Table 1 and Figure 3 that the tractor, when equipped with rubber tires, has a much less rolling resistance than when equipped with steel wheels and spade lugs. This is true both on sod and plowed ground. It is of further interest to note that the difference in rolling resistance between the two types of wheels is greater on sod than it is on plowed ground. Furthermore, the rolling resistance of the rubber-tired tractor on plowed ground was less than of the steel-wheel tractor on sod.

The rolling resistance for both types of wheels is less on sod than it is on plowed ground.[1] This difference is due primarily to the fact that the tractor on plowed ground continually climbs an incline because of the low bearing

[1]Care must be exercised not to confuse tractive efficiency with rolling resistance.

capacity of plowed soil. In effect, therefore, the wheels are passing up a grade which naturally increases the rolling resistance to a great extent. The steepness of this grade will depend upon several factors such as width of rim or tire, diameter of wheel, and the extent to which the tractive surface is depressed by the wheels. The unevenness or roughness of the ground surface is another factor influencing the rolling resistance. This factor is discussed in detail under "Draft of Farm Wagons".

TABLE 1.—Rolling Resistance of Tractor

Wheel	Tractive surface	Distance traveled	Time required	Miles per hour	Force required to pull tractor	H. P.
		Ft.	*Sec.*		*Lb.*	
Steel...............	Sod	190.4	60	2.16	827	5.24
Steel...............	Sod	268.1	60	3.05	911	7.64
Steel...............	Sod	369.3	60	4.21	878	10.81
Rubber-tired	Sod	276.5	60	3.14	273	2.53
Rubber-tired	Sod	390.2	60	4.44	265	3.45
Steel...............	Plowed ground	188.5	60	2.14	1042	6.46
Steel...............	Plowed ground	235.0	60	2.67	1150	9.08
Steel...............	Plowed ground	313.0	60	3.56	1102	11.54
Rubber-tired	Plowed ground	197.2	60	2.24	557	3.66
Rubber-tired	Plowed ground	260.0	60	2.95	592	5.13
Rubber-tired	Plowed ground	308.5	60	3.72	739	6.93

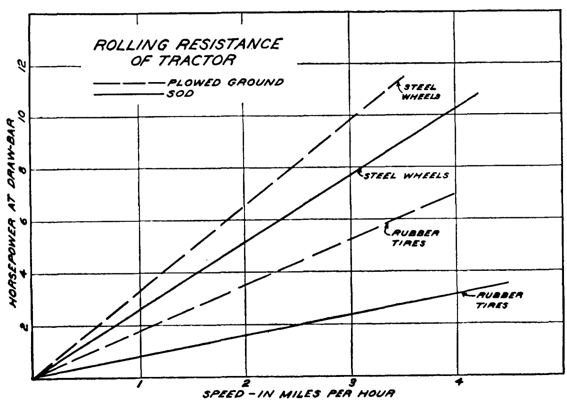


Fig. 3

Another factor exists which is very important from the standpoint of the tractor wheels. When a wheel is equipped with lugs or other penetrating devices, it requires a force to push them into the ground in addition to removing them. With this additional force to push the lugs into the ground and to remove them, more power is consumed. This is one of the major reasons why the difference in rolling resistance between the steel wheel with lugs and the rubber tire is greater on sod than it is on plowed ground. More effort is required to force the lugs into sod than into soft plowed ground. The rapidity at which the lugs are forced into and lifted from the ground is another important factor.

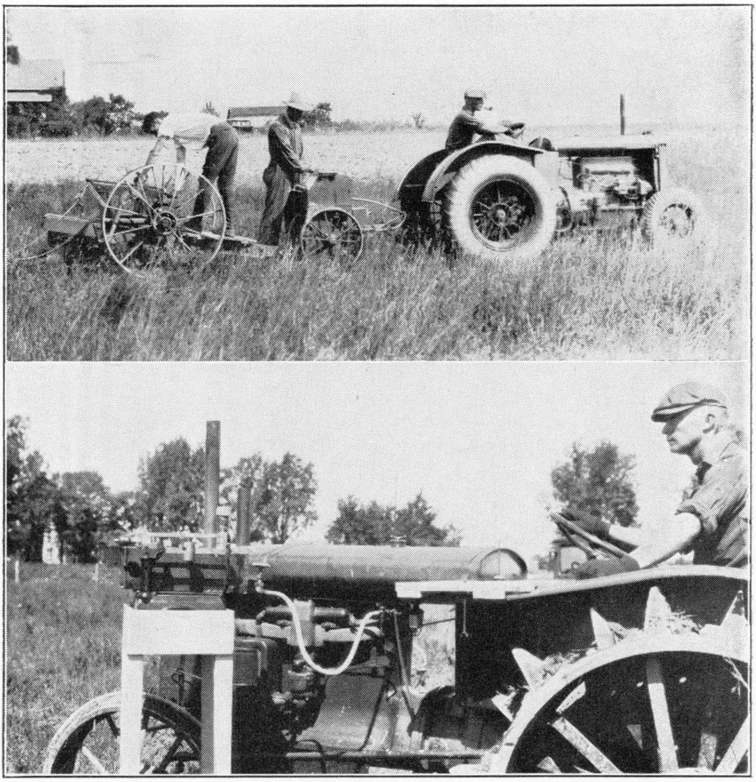


Fig. 4.—*Top*—Making a fuel and draw-bar test on timothy sod. *Bottom*—Weighing the fuel at the end of a test

Table 2 serves to give a comparison of the rolling resistance of the two types of wheels on sod and plowed ground.

TABLE 2.—Comparative Rolling Resistance of Tractor When Equipped with Steel Wheels and Lugs and with Low-pressure Pneumatic Tires

Wheel	Tractive surface	Speed	Horsepower to move tractor
		Miles per hour	
Steel	Sod	2	5.1
Rubber-tired	Sod	2	1.6
Steel	Sod	3	7.7
Rubber-tired	Sod	3	2.4
Steel	Sod	4	10.2
Rubber-tired	Sod	4	3.2
Steel	Plowed ground	2	6.5
Rubber-tired	Plowed ground	2	3.5
Steel	Plowed ground	3	9.8
Rubber-tired	Plowed ground	3	5.3
Steel	Plowed ground	3½	11.4
Rubber-tired	Plowed ground	3½	6.2

FUEL CONSUMPTION

This series of tests was conducted for the purpose of determining the fuel consumption of the tractor when equipped with either steel wheels or low-pressure rubber tires and operating on both sod and plowed ground.

The load to the tractor was provided by pulling a subsoiler through the ground at different depths and at various speeds or rates of travel.

A course of 750 feet in length was measured off in the field for the test. At each end of this course the dynamometer was checked in and out and the fuel turned on or off as the occasion required. A run was made in both directions, which constituted a test of 1500 feet in length. This was done to compensate for any existing grades or irregularities in soil types or coverage.

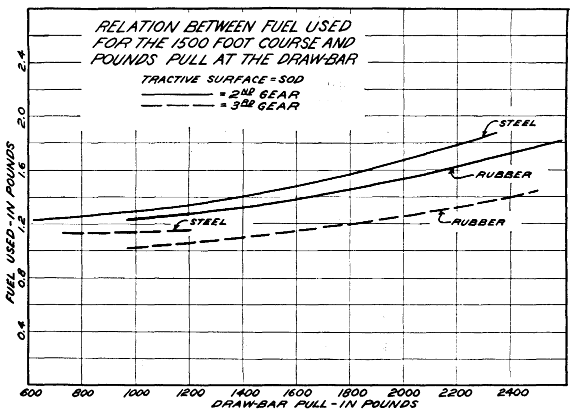
The fuel for the tractor was supplied from the regular tank for "dead-heading" and when making necessary adjustments. For the actual test the fuel was obtained from an auxiliary tank attached to the tractor for this purpose only. The tractor was operated both in second and third gears.

Table 3 gives the tabulated results for the 1500-foot course on sod and plowed ground.

TABLE 3.—Fuel Consumption and Horse Power Delivered

Wheel	Gear	Time Seconds	Miles per hour	Drawbar pull Pounds	H. P. at drawbar	Fuel used Pounds per 1500 ft.	Fuel used Pounds per Hour	Fuel used Pounds per H. P. hour at drawbar
Sod ground								
Steel	2nd	262.0	3.90	606	6.30	1.24	17.05	2.73
Steel	2nd	282.2	3.63	1335	12.92	1.39	17.74	1.37
Steel	2nd	344.0	2.97	1980	15.61	1.71	17.90	1.15
Steel	2nd	352.4	2.90	2220	17.18	1.71	17.46	1.02
Steel	2nd	397.4	2.57	2333	16.00	1.88	17.04	1.06
Rubber-tired	2nd	304.0	3.37	966	8.68	1.23	14.57	1.68
Rubber-tired	2nd	312.8	3.27	1580	13.76	1.41	16.24	1.18
Rubber-tired	2nd	328.0	3.12	2210	18.36	1.65	18.12	0.99
Rubber-tired	2nd	363.4	2.81	2430	18.22	1.88	18.62	1.02
Rubber-tired	2nd	365.0	2.80	2620	19.50	1.70	16.77	0.86
Steel	3rd	201.6	5.08	675	9.14	1.16	20.72	2.27
Steel	3rd	240.0	4.26	1183	13.42	1.12	16.80	1.25
Rubber-tired	3rd	198.6	5.15	953	13.07	1.02	18.50	1.41
Rubber-tired	3rd	225.4	4.54	1620	19.62	1.16	18.53	0.95
Rubber-tired	3rd	266.6	3.84	2215	22.62	1.36	18.37	0.81
Rubber-tired	3rd	310.8	3.29	2500	21.93	1.42	16.46	0.75
Plowed ground								
Steel	2nd	300.0	3.41	700	6.37	1.43	17.15	2.69
Steel	2nd	308.0	3.32	825	7.28	1.54	18.00	2.46
Steel	2nd	451.0	2.27	1160	7.03	2.20	17.56	2.50
Rubber-tired	2nd	311.4	3.28	678	5.94	1.52	17.57	2.96
Rubber-tired	2nd	328.6	3.11	796	6.60	1.56	17.10	2.59
Rubber-tired	2nd	359.0	2.85	1130	8.58	1.68	16.85	1.97
Steel	3rd	235.4	4.35	700	8.12	1.20	18.35	2.26
Steel	3rd	271.8	3.77	815	8.19	1.40	18.55	2.27
Rubber-tired	3rd	222.0	4.61	700	8.59	0.98	15.90	1.81
Rubber-tired	3rd	247.0	4.14	859	9.48	1.22	17.78	1.87
Rubber-tired	3rd	265.4	3.85	1104	11.32	1.34	18.18	1.61

If the rolling resistance of the tractor is lower with rubber tires than with steel wheels and lugs, it is reasonable to expect greater fuel economy with the rubber tires than with the steel wheels. Figures 5 and 6 point this out very conclusively. At practically all loads and on both sod and plowed ground, the fuel consumption was less for the rubber-tired tractor. Only on plowed ground, at the light draw-bar pull, did the steel-wheel excel the rubber-tired tractor in fuel economy. It is of further interest to note that the rubber-tired tractor, operating in third gear, had greater fuel economy, both on sod and plowed ground than the steel wheel in second gear. The third gear performance of the steel wheel was very erratic and excessive slippage at this speed curtailed greatly the accomplishment of the heavier draw-bar pulls. Another outstanding fact observed in the field was that for third gear the steel-wheel equipment produced a maximum draw-bar pull of only 815 pounds on plowed ground and 1195 pounds on sod with excessive slippage. The rubber-tired tractor in third gear produced a maximum draw-bar pull of 2500 pounds in sod and 1104 pounds in plowed ground.



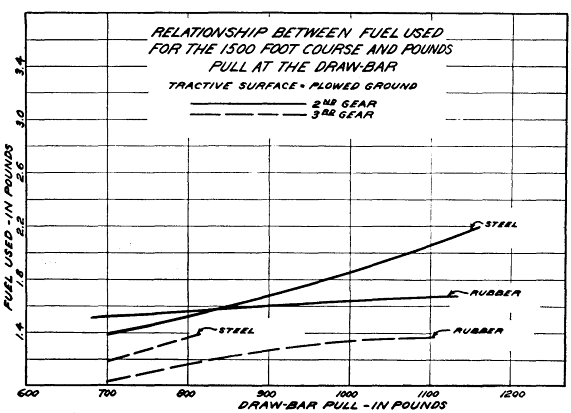


Fig. 5

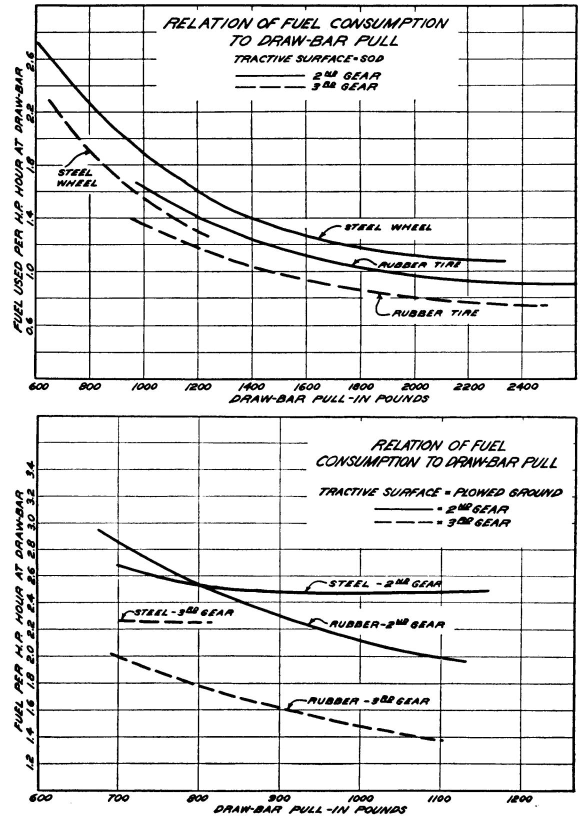


Fig. 6

TABLE 4.—Comparisons on Fuel Consumption

Draw-bar pull	Pounds fuel for 1500-ft. travel			Pounds fuel per H. P. hour at draw-bar		
	Steel	Rubber	Rubber	Steel	Rubber	Rubber
Pounds	2nd gear	2nd gear	3rd gear	2nd gear	2nd gear	3rd gear
Sod ground						
1000	1.31	1.24	1.02	1.89	1.64	1.35
1400	1.42	1.33	1.11	1.39	1.24	1.03
1800	1.57	1.46	1.21	1.18	1.03	0.85
2200	1.79	1.62	1.33	1.10	0.92	0.78
2400	....	1.72	1.41	....	0.90	0.75
Plowed ground						
700	1.40	1.50	1.01	2.68	2.85	2.00
800	1.51	1.55	1.16	2.52	2.52	1.78
900	1.68	1.61	1.26	2.48	2.30	1.62
1000	1.85	1.64	1.32	2.47	2.11	1.48
1100	2.05	1.65	1.37	2.48	1.99	1.38

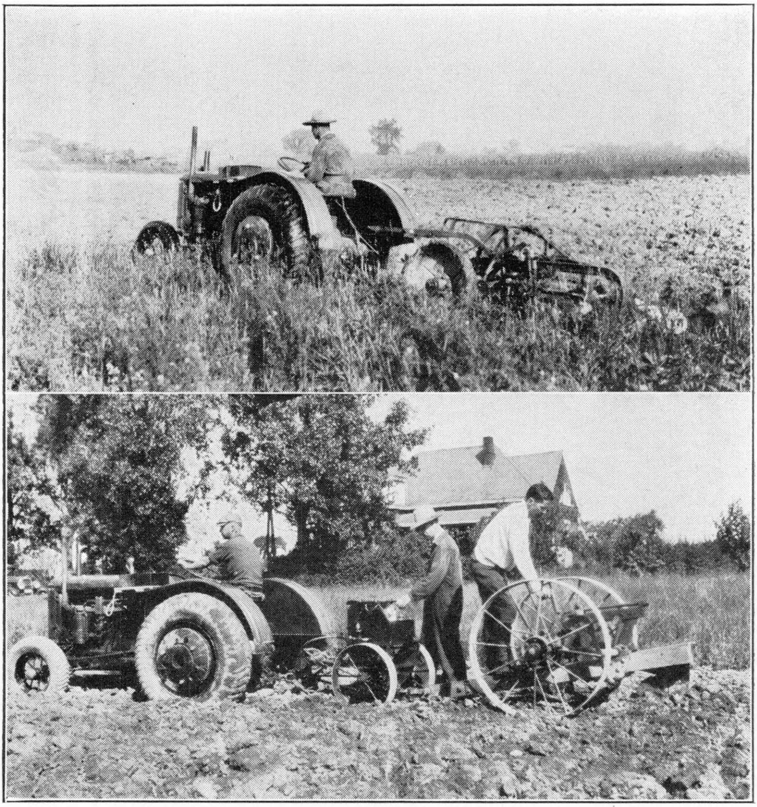


Fig. 7.—*Top*—Plowing in the morning when the grass was wet. *Bottom*—Testing for draw-bar pull on plowed ground

PLOWING TEST

The purpose of this test was to determine the practicability of the rubber-tired tractor for plowing, in addition to obtaining further fuel consumption data for this farm operation. The field was laid out in two lands, each 700 feet in length. The tests were conducted in part on each plot in order to compensate for any irregularities in soil type, texture, coverage, or grades. Half of the first and second plots was plowed with the steel wheels and lugs and the remainder with rubber-tired equipment.

The work was done on a field of sod which consisted of a heavy growth of timothy and alfalfa. No attempt was made to operate the draw-bar dynamometer between the tractor and plow. However, a very careful check was maintained on the depth and width of plowing in order to hold the average load nearly uniform for both tests. The work was done in as short a time as possible so as to have conditions comparable. The same tractor and two-bottom plow were used for all tests. After the tests were finished with the steel wheels, they were removed and the rubber tires and weights installed. The fuel records were kept in the same manner as on the previous fuel consumption tests. The tractor was operated in second gear for the steel-wheel equipment because in preliminary tests it was found that the tractor could not pull the plows in third gear without shifting into second gear. The tractor, when equipped with rubber tires, was able to pull the plows at all times in third gear.

From Table 5 it is evident that, in addition to using 23.8 per cent less fuel than the steel-wheel tractor, the rubber-tired tractor was able to plow 27.3 per cent more ground per hour because of the higher speed. By the higher speed, greater granulation of soil was obtained. For spring plowing this factor may mean a saving in subsequent tillage operations for preparation of the seedbed.

TABLE 5.—Compilation of Plowing Data

	Steel wheel	Rubber tires
Length of plots, feet	700	700
Width of plots, feet	48.9	49.0
Area plowed, square feet	34255.9	34300.0
Average depth of plowing, inches	6.89	6.82
Time, minutes	45.08	35.30
Rate of travel, miles per hour	3.53	4.50
Acres per hour	1.048	1.33
Fuel used, pounds	12.81	9.72
Fuel used, pounds per acre	16.26	12.37

Very little trouble was experienced in securing sufficient traction with the rubber tires. This was true even in the mornings when the grass was still wet and the surface of the soil somewhat slippery. At one point, however, where barnyard manure had been spread over the surface of the ground, considerable slippage was experienced. When the rubber tires were first installed it was observed that the tractor had a tendency to run slightly closer to the plowed ground, making the plow cut a narrower furrow. This was remedied by changing the hitch on the plow. The operator of the tractor found that the rubber-tired outfit was very easy to handle and that it rode more easily than did the steel-wheel outfit.

TRACTIVE EFFICIENCY

Another series of tests was run to determine the draw-bar pull of the tractor equipped with steel wheels and lugs and with low-pressure rubber tires. These tests were made on both sod and plowed ground. A subsoiler was used to furnish the load or draft for the tractor. A depth regulator on the subsoiler was the means of regulating the load for the tractor. To record the pounds pull at the draw-bar, distance traveled, and the time required for test, the dynamometer was hooked between the tractor and the subsoiler.

The tests were made with the tractor operated both in second and third gears. The load was applied to the tractor to a point where excess slippage or travel reduction occurred. The third gear performance of the steel wheel was very inconsistent due to irregularities in travel reduction.

From Figure 8 it is quite evident that the rubber-tired wheels on sod provide for a greater maximum draw-bar pull than do the steel wheels and lugs. This is true both in second and third gears—the difference being much greater in third gear. In third gear the steel wheel was unable to provide for a draw-bar pull much above 1200 pounds when excessive slippage or travel reduction took place. The draw-bar pull of the rubber-tired tractor reached 2500 pounds before any great amount of wheel slippage was perceptible.

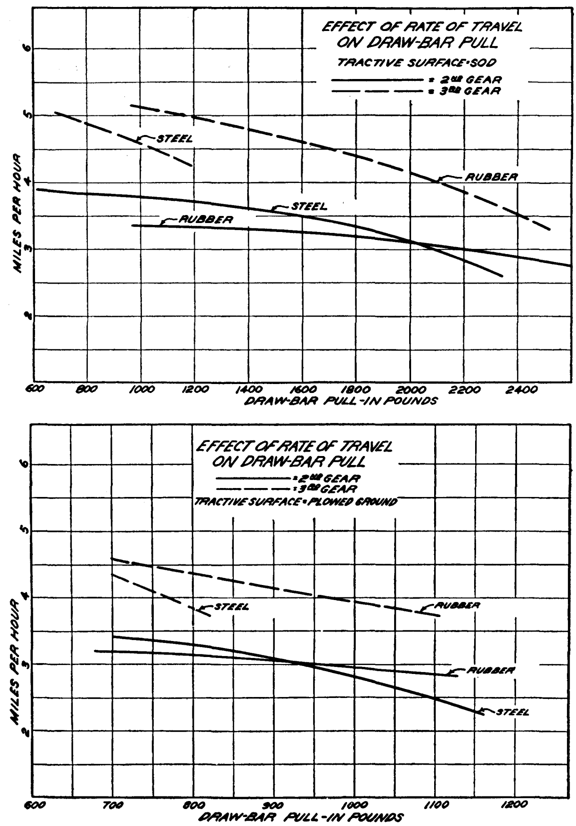


Fig. 8

As the speed or rate of travel is decreased, the draw-bar pull of the steel wheel decreases more rapidly than does that of the rubber tire. This is due in part to the cohesive ability of the rubber tire on the surface of the ground at the heavier loads or draw-bar pull. As would be expected, greater speeds were obtained on sod than on plowed ground before excessive slippage took place. The same general results are obtained on plowed ground, although in second gear the steel wheel exerted a slightly higher maximum draw-bar pull than did the rubber tire. Again the steel wheel showed a low maximum draw-bar pull in third gear, amounting to only 815 pounds. Above this point the slippage was exceedingly high.

The horsepower at the draw-bar may be increased in two ways: (1) By increasing the draw-bar pull and (2) by increasing the rate of travel. Both of these factors depend directly upon the tractive ability of the wheels and the power of the engine. With the increased speed obtained by the rubber tires, a much greater horsepower was developed with a minimum travel reduction. This accounts in a large part for the fuel economy at the higher speeds as indicated under fuel consumption tests. The rubber tire, therefore, shows under favorable conditions that it can transmit the engine horsepower more efficiently to the draw-bar than can steel-wheel equipment and that it is more pronounced at the higher rates of travel.

A greater draw-bar pull can be attained with the steel wheels and lugs at the lower speeds or rates of travel up to a point near to the maximum pull. The steel wheels then begin to drop much more rapidly in draw-bar pull than does the rubber tire. See Figure 9.

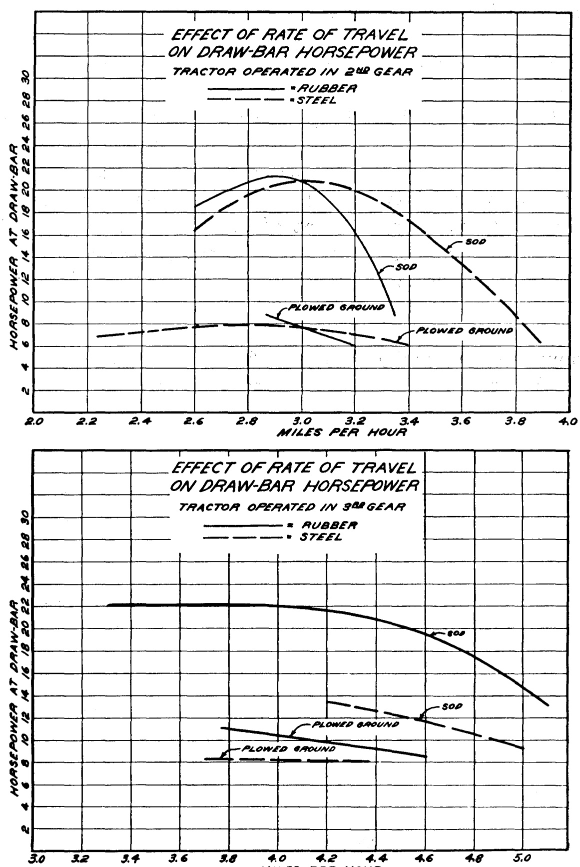


Fig. 9

The question now arises as to why the low-pressure pneumatic tire has such a surprisingly high tractive efficiency as compared to steel wheels and lugs. As mentioned previously, one of the major reasons for the lowering of tractive efficiency with steel wheels and lugs is the fact that power is required to force the picks or lugs into the ground and to remove them. Of course, if it were not for these penetrating devices, very little friction or "hold" with the ground would be secured.

From the basic conception of friction between two surfaces, the area of contact does not influence the amount of friction providing the other factors remain equal. Friction does depend, however, on the character of the faces in contact and the total pressure normal to the faces. Friction is always greater just before the two surfaces in contact begin to slip past one another. As soon as movement begins, friction between the two surfaces becomes less. This is the reason why it is practically impossible to move a "stalled" tractor after a wheel has begun to slip. On a dry surface rubber has a higher coefficient of sliding friction than does a smooth piece of steel on the same surface. As the surfaces become wet the difference in coefficient of friction of the two materials with the wet surface becomes less because of the fact that the rubber will slip more easily.

It is evident, therefore, that the greater area of contact of the rubber tire with the ground is not a factor in creating higher tractive efficiency. If we inflate a smooth rubber tire to a point where the load applied upon it would not depress the tire, we would have practically the same thing as a smooth steel wheel. The static or sliding coefficient of friction would be low in both cases. To increase static frictional resistance, the surfaces are made rough—by placing picks in the steel wheel and by roughing the tread of a rubber tire. In this case the steel wheel would have the greater resistance but would require more power to accomplish it.

Suppose now that the rubber tire is deflated to a low air pressure as shown in Figure 10. The irregularities in the ground surface are depressed into the tire, giving a greater total pressure normal to the faces in contact. This might be considered as similar to the steel wheel but in a reverse situation—the roughness of the ground acting as the picks and the rubber tire as the surface of the ground. In this case, however, the power consumed is less, due to the fact that the load is carried on a much more even plane, thereby eliminating a vertical lift of the tractor itself. This is undoubtedly the major reason for the high tractive ability of the rubber tire. The tread of the tire is pushed down into the depressions on the ground surface, and, as the load on the tractor increases, the total pressure on the surfaces of the ground normal to the face of the tire also increases. Evidence of this fact is illustrated by the greater draw-bar pull exerted by the rubber-tired tractor over the steel-wheel tractor.

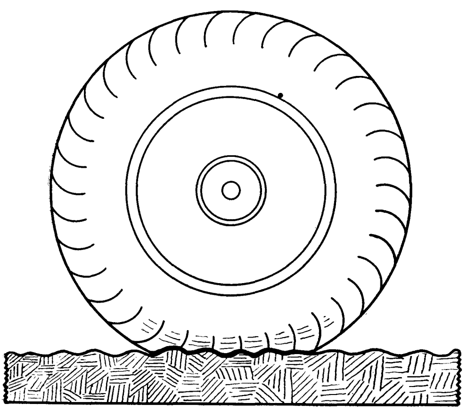


ILLUSTRATION SHOWING HOW LOW PRESSURE TIRE MAKES CONTACT WITH THE UNEVEN GROUND SURFACE

Fig. 10

There is another factor which may have an influence in increasing frictional resistance. As the rubber tire revolves there is undoubtedly a vacuum created between the rubber tire and the surface of the ground and as the tire breaks this vacuum there is a tendency to create an increased pressure between the two surfaces in contact. This should be greater at the higher speeds or rates of travel.

LIFE OF RUBBER TIRES

Low-pressure pneumatic tires for tractors have not been in use long enough to determine their actual life, but some data are available which give a fairly close estimate as to their wearing qualities, although they will depend, as in the case of other pieces of farm machinery, upon the appreciation of the operator.

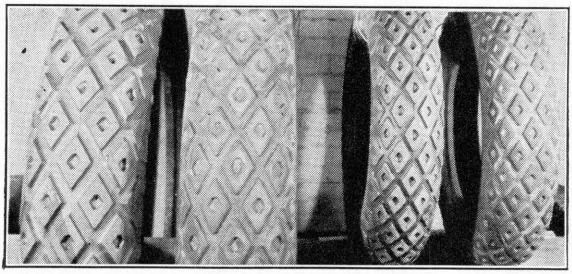
During the month of April 1933, a tractor owned and operated by the University farm was equipped with low-pressure pneumatic tires. From that date up to the present time a very careful record has been kept on the number of hours of use for these tires together with the various farm operations done by the tractor.

From April 1, 1933, to the end of February 1935 the tractor with the rubber-tired equipment has been used 1349 hours. During this time the tractor has furnished power—either belt or draw-bar—for the following farm operations: Plowing, disking, harrowing, cultivating, cultipacking, corn picking, drilling, raking, hoeing, loading and mowing hay, binding grain, digging potatoes, packing ensilage in pit silo, and other necessary farm jobs.

There are several factors which determine the life of tires and which may be enumerated as follows:

1. Abrasive wear.
2. Chipping.
3. Punctures and blowouts.
4. Chemical decomposition.

As will be seen from Figure 11, there is little evidence of abrasive wear. It is quite logical to expect much less wear through this medium on farm tractor tires than on truck or auto tires, because of decreased velocity. At the higher road speeds to which a truck tire is subjected, there is nearly always a constant slipping action between the tire and the road surface which is followed by the generation of heat. This condition generally results in wear of an abrasive nature.



New Old New Old
REAR TIRES FRONT TIRES
Fig. 11.—Compare the tires for wear

The tires seem to have suffered the most wear by chipping, although not of a serious nature. The corners on the tread have chipped slightly due to contact with sharp stones or similar materials on the surface of the ground.

The side walls are entirely free of any chipping. The rear tire, when new, weighed 98.3 pounds. At the end of 1349 hours of use the tire weighed 94.25 pounds, indicating a decrease in weight of 4.05 pounds. Undoubtedly, a large percentage of this loss in weight is due to the chipping of the tread. Very little difference in loss of weight existed between the tire regularly used in the furrow and the one on the land. The front tire decreased in weight 0.5 of a pound.

During the full time the tires have been on test, only two punctures have been experienced, one on a front tire and one on a rear tire. The front tire puncture was caused by a nail and the rear tire puncture by some large, sharp object which cut deeply into the tire. Neither of the punctures caused any immediate trouble as the air in the tire was not released instantly. The valve stem on one of the front tires was torn from the inner tube. Due to the fact that on this particular type of tractor the two front wheels run close together, considerable material, particularly stones, was picked up or rolled around between the two wheels. The valve stems, being on the inside, were subjected to considerable abuse by this material and eventually became very much weakened. No further trouble has been experienced since the valve stems were placed on the outside of the wheels. Very little evidence is seen of chemical dĕcomposition of the tires. Barnyard manure or weathering seems to have little effect upon them.

GENERAL OBSERVATIONS

There are a number of other factors of a general nature which were observed in the operation of the two types of wheel equipment. When the soil is dry much less dust is created by the rubber-tired equipment. Evidence of this is found by weighing the amount of dust found in the air cleaner of the engine at the end of a 24-hour run. Under most conditions the rubber-tired tractor rides easier than when the tractor is equipped with steel wheels and lugs. However, if the ground is ridged badly, considerable "bouncing" is experienced with the rubber-tired equipment. This can be partially relieved by inflating the rear tires a slight amount. The rubber-tired equipment offers a cushion to shocks. This is particularly true on hard tractive surfaces.

Rubber tires pick up and carry less loose surface material than do the steel wheels with picks. This was plainly evident during the corn picker tests when the surface of the ground was more or less sticky and covered with an abundance of loose leaves and stalks. This was also true in plowing meadows where the land wheel of the steel-wheel tractor has a tendency to fill up between each pick or lug in the wheel.

For most farm operations, therefore, the tractor equipped with low-pressure pneumatic tires is very satisfactory. It is especially desirable for transportation work, mowing or making hay, cultivating corn, seeding or planting, plowing, and combining grain, or in fact any operation where the tractive surface is not too wet or sticky or covered with such material as wet barnyard manure. Under adverse conditions chains may provide temporary relief but probably the best practice to follow is to stay off the ground until it is in fit shape to be worked. For road work at the higher speeds, the braking systems of tractors will undoubtedly need to be redesigned for quick stopping.

WHEEL AND BEARING EQUIPMENT FOR FARM WAGONS AND TRAILERS

Without question rubber tires for tractors have many advantages over the steel wheel for farm use. First and foremost is the fact that the tractor can now be used on the highways without interruption from the highway authorities and therefore the task of removing and replacing wheel lugs is eliminated.

One important factor in reducing the cost of each day's service of any machine is to use it a greater number of days per year. In other words, increase the utility value of the machine and depreciation is lowered. With rubber-tired equipment the tractor will undoubtedly be used for transportation purposes to a greater degree than in the past. A large part of the transportation work which was originally done by some other means necessitating an additional investment will very likely be done by the rubber-tired tractor. Indications point that in the future it will be possible to travel at least 25 miles per hour on paved highways.

Wagons or trailers with the rubber-tired tractors as a means for motive power will undoubtedly become more common. In many cases the ordinary farm wagon may be brought into further use. Hard-surfaced roads, however, are extremely hard on machines equipped with steel wheels and also create a further danger of damaging the transported product. It seems, therefore, in order to secure the most out of rubber-tired equipment for tractors that wagons and trailers should be so equipped in order to meet the higher speeds in transportation work. With this in view the Department of Agricultural Engineering of the Ohio Agricultural Experiment Station, in cooperation with the wagon, wheel, and rubber-tire manufacturers, conducted a series of tests on the draft of wheel equipment for farm wagons and trailers.

Several types of wheels and bearings were used, specifications of which are listed in Table 6.

TABLE 6.—Specifications of Types of Wheels and Bearings Used

Wood and steel wheels

Type of wheel	Diameter		Rim width	Type of bearing	Weights per set of four
	Front	Rear			
	In.	*In.*	*In.*		*Lb.*
Wood	40	44	3	Wagon skein	....
Wood	44	44	4	Wagon skein	....
Steel	28	34	4	Wagon skein	260
Steel	28	34	4	Plain roller	296
Steel	28	34	5	Plain roller	350
Steel	28	34	6	Plain roller	390
Steel	28	34	5	Plain	354
Steel	32	36	5	Plain roller	386
Steel	32	36	5	Taper roller	382

Rubber-tired wheels

Type of wheel	Size	Inflation	Type of bearing	Weights per set of four (wheels and tires)
		Lb.		*Lb.*
Solid-cushion tire*	30 x 6.00	....	Plain roller	640
High-pressure pneumatic tire	30 x 5.00	60	Plain roller	480
Low-pressure pneumatic tire	31 x 7.50	30	Plain roller	292

*The solid-cushion tire is a rubber tire similar to the solid type but for the fact that it contains a dead-air space in the center of the tire for cushioning effects.

The various types of wheels were tested over five tractive surfaces: Meadow, cultivated soil, and cinder, gravel, and concrete roads. The rates of travel ranged from 2½ to 20 miles per hour, depending upon the tractive surface over which the load was transported. The net loads varied from 2,000 to 5,000 pounds.

With this equipment it was possible to study the following relationships:

1. The relative draft of various loads at various speeds on five tractive surfaces.

2. The relative draft of steel and rubber-tired equipment for wagons or trailers over these five tractive surfaces, together with their effect on soil compaction.

3. Diameters and widths of rim with reference to draft required.

4. The effect of plain, roller, and wagon skein type of bearings on the draft of the wagon.

Throughout all of these tests the wagon hitch was adjusted vertically in order to compensate for the various heights of wheels and tractive surfaces. This was accomplished by making a series of hitch tests in order to determine the true line of draft of the wagon in the vertical plane.

DRAFT TESTS ON VARIOUS TRACTIVE SURFACES

MEADOW TESTS

When a machine mounted on wheels of the conventional type is moved over a soft surface, the wheels tend to cut in or penetrate through this surface.

TABLE 7.—Draft Tests on Meadow

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Low-pressure..	31	7.50	30	Plain roller	1275	....	1275	2½	42.7
Low-pressure..	31	7.50	30	Plain roller	1275	2000	3275	2½	81.7
Low-pressure..	31	7.50	30	Plain roller	1275	3500	4775	2½	132.4
Low-pressure..	31	7.50	30	Plain roller	1275	5000	6275	2½	159.5
Low-pressure..	31	7.50	30	Plain roller	1275	2000	3275	3¼	97.0
Low-pressure..	31	7.50	30	Plain roller	1275	3500	4775	3¼	120.0
Low-pressure..	31	7.50	30	Plain roller	1275	5000	6275	3¼	174.7
High-pressure.	30	5.00	50	Plain roller	1463	....	1463	2½	42.9
High-pressure.	30	5.00	50	Plain roller	1463	2000	3463	2½	90.3
High-pressure.	30	5.00	50	Plain roller	1463	3500	4963	2½	145.3
High-pressure.	30	5.00	50	Plain roller	1463	5000	6463	2½	190.5
High-pressure.	30	5.00	50	Plain roller	1463	2000	3463	3¼	90.0
High-pressure.	30	5.00	50	Plain roller	1463	3500	4963	3¼	130.7
High-pressure.	30	5.00	50	Plain roller	1463	5000	6463	3¼	220.6
Solid-cushion ..	30	6.00	....	Plain roller	1623	....	1623	2½	56.6
Solid-cushion ..	30	6.00	....	Plain roller	1623	2000	3623	2½	136.8
Solid-cushion ..	30	6.00	....	Plain roller	1623	3500	5123	2½	175.0
Solid-cushion ..	30	6.00	....	Plain roller	1623	5000	6623	2½	260.2
Solid-cushion ..	30	6.00	....	Plain roller	1623	2000	3623	3¼	123.2
Solid-cushion ..	30	6.00	....	Plain roller	1623	3500	5123	3¼	193.0
Solid-cushion ..	30	6.00	....	Plain roller	1623	5000	6623	3¼	239.6
Steel...........	28 and 34	5.00	....	Plain roller	1325	....	1325	2½	50.2
Steel...........	28 and 34	5.00	....	Plain roller	1325	2000	3325	2½	119.6
Steel...........	28 and 34	5.00	....	Plain roller	1325	3500	4825	2½	232.7
Steel...........	28 and 34	5.00	....	Plain roller	1325	5000	6325	2½	418.3
Steel...........	28 and 34	5.00	....	Plain roller	1325	2000	3325	3¼	133.9
Steel...........	28 and 34	5.00	....	Plain roller	1325	3500	4825	3¼	189.1
Steel...........	28 and 34	5.00	....	Plain roller	1325	5000	6325	3¼	347.5

In order to move forward the wheels are, therefore, forced to climb an incline in their effort to reach the top of the surface. The only reason that the wheel rim does not reach the surface is because the bearing capacity of the soil is not of sufficient strength to withstand the load. The slope or grade of this incline depends on the depth that the wheels cut through the surface. The depth of penetration varies according to the load carried by the wheels and the bearing capacity of the tractive surface.

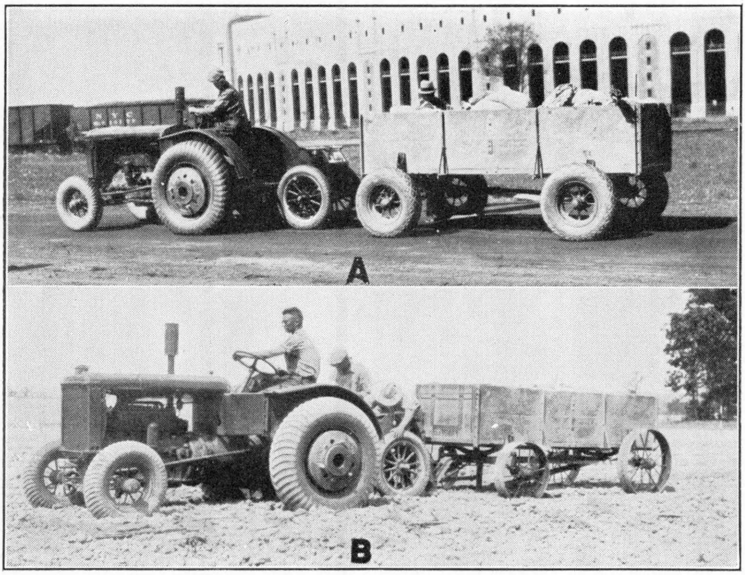


Fig. 12.—*A*—Making a draw-bar test on cinder road.
***B*—Making a draw-bar test on cultivated soil**

On cultivated soil or on meadow, the "cutting-in" action of the wheels is probably the greatest single factor influential in creating excessive draft. Cultivated soil has a very low bearing capacity, which will vary according to the type and moisture content of the soil. Meadow also has a low bearing capacity, although not to the extent of cultivated soil. The difference in draft between soil and meadow for a wagon with steel wheels and a 6000-pound gross load traveling 2½ miles per hour was 790 pounds. This difference can be attributed only to the lower bearing capacity of cultivated soil.

Several types of wheel rims have been designed to reduce penetration into tractive surfaces, such as cultivated soil or meadow. Penetration will also be reduced by limiting the shearing capacity of the rim. A wheel with a straight side rim and sharp corner will have a greater ability to shear than one with a round corner. The greater the curve on the corner of the rim, the less will be the shearing capacity.

One reason why the pneumatic rubber tire required much less draft than the steel wheel on the tractive surfaces having a low bearing capacity is that there are no sharp corners on the pneumatic rubber tire; hence, the ability to shear is extremely low. From Figure 13 it is quite evident that the low-pressure pneumatic tire offers considerable saving in draft over steel-wheel equipment. The meadow over which the tests were made was rather dry and hard, and therefore the factor of penetration was of little importance. The surface of the meadow, however, was very uneven or rough. This is an additional factor favorable to the use of the rubber tire, both in regard to draft and the jolting of the load.

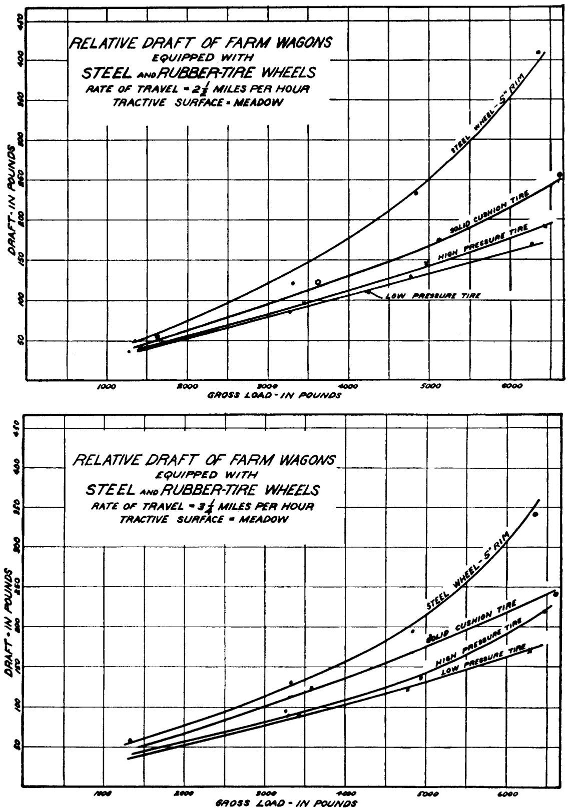


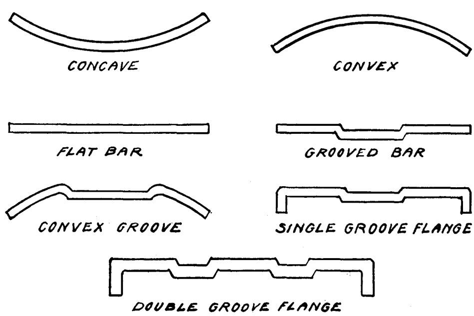
Fig. 13

CULTIVATED SOIL TESTS

The soil was disked previous to conducting the tests in order to eliminate any hard spots which might have been encountered; the soil, therefore, was loose and dry.

TABLE 8.—Draft Tests on Cultivated Soil

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Low-pressure....	31	7.50	30	Plain roller	1275	....	1275	2½	131.0
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	2½	354.5
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	2½	522.5
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	2½	596.0
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	3¼	320.5
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	3¼	492.5
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	3¼	780.5
High-pressure...	30	5.00	60	Plain roller	1463	....	1463	2½	200.0
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	2½	543.0
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	2½	775.5
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	2½	885.0
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	3¼	542.5
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	3¼	875.0
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	3¼	1279.5
Solid-cushion	30	6.00	......	Plain roller	1623	....	1623	2½	294.0
Solid-cushion	30	6.00	......	Plain roller	1463	2000	3623	2½	652.0
Solid-cushion	30	6.00	......	Plain roller	1463	3500	5123	2½	881.5
Solid-cushion	30	6.00	......	Plain roller	1463	5000	6623	2½	1029.0
Solid-cushion	30	6.00	......	Plain roller	1463	2000	3623	3¼	740.0
Solid-cushion	30	6.00	......	Plain roller	1463	3500	5123	3¼	1109.0
Solid-cushion	30	6.00	......	Plain roller	1463	5000	6623	3¼	1356.5
Steel............	28 and 34	5.00	.....	Plain roller	1325	....	1325	2½	205.0
Steel............	28 and 34	5.00	......	Plain roller	1325	2000	3325	2½	731.5
Steel............	28 and 34	5.00	......	Plain roller	1325	3500	4825	2½	1031.0
Steel............	28 and 34	5.00	.....	Plain roller	1325	5000	6325	2½	1175.0
Steel............	28 and 34	5.00	......	Plain roller	1325	....	1325	3¼	240.3
Steel............	28 and 34	5.00	......	Plain roller	1325	2000	3325	3¼	686.0
Steel............	28 and 34	5.00	......	Plain roller	1325	3500	4825	3¼	911.0
Steel............	28 and 34	5.00	......	Plain roller	1325	5000	6325	3¼	1188.0



COMMON TYPES OF WHEEL RIMS

Fig. 14

From Figure 15 it is again apparent that the low-pressure tire requires less draft than any of the other types of wheels. For a 6000-pound gross load traveling at the rate of 2½ miles per hour there was a difference in draft of 561 pounds in favor of the low-pressure tire over the steel wheel. This is a large saving in draft and this can be attributed largely to the ease with which the steel wheel shears into the soil, thereby increasing the draft. At 3¼ miles per hour the difference in draft between the steel wheel and low-pressure tire was 370 pounds at the 6000-pound load. Again the saving of draft was in favor of the low-pressure tire. The high-pressure pneumatic tire ranked next, followed by the steel wheel and then the solid-cushion tire.

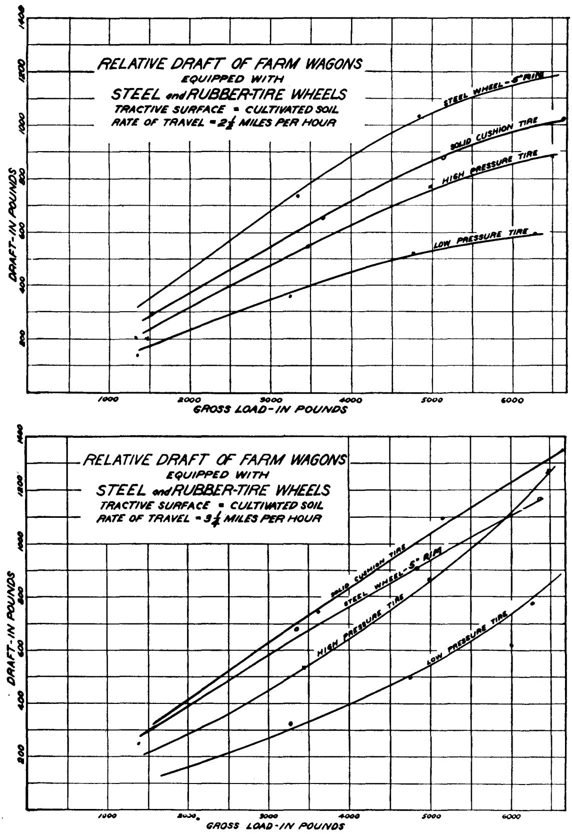


Fig. 15

Figure 16 shows the shearing effect, together with depth of penetration, of both steel and pneumatic rubber-tired wheels. Both types of wheels were equally loaded and the tests run on the same soil with the same moisture content. Note that the low air pressure of 10 pounds penetrates to a maximum depth of nine-tenths of one inch, the 50-pound pressure to a depth of one and eight-tenths inches, and the steel wheel to a depth of two and two-tenths inches. The tire with the low air pressure distributes the load over a greater area by having a wider track than either of the other two. A concentrated load will pack a given amount of soil to a greater degree than when an equal load is distributed over a larger area.

CINDER ROAD TESTS

The low-pressure tire again requires less draft than any of the other types of wheels, the only exception being at 20 miles per hour where the high-pressure tire showed a slightly greater advantage. Very little "cutting-in" action takes place on most cinder roads, but the roughness or unevenness of the road surface creates a condition which makes for less draft by the pneumatic tire over the steel wheel or even the solid-cushion tire.

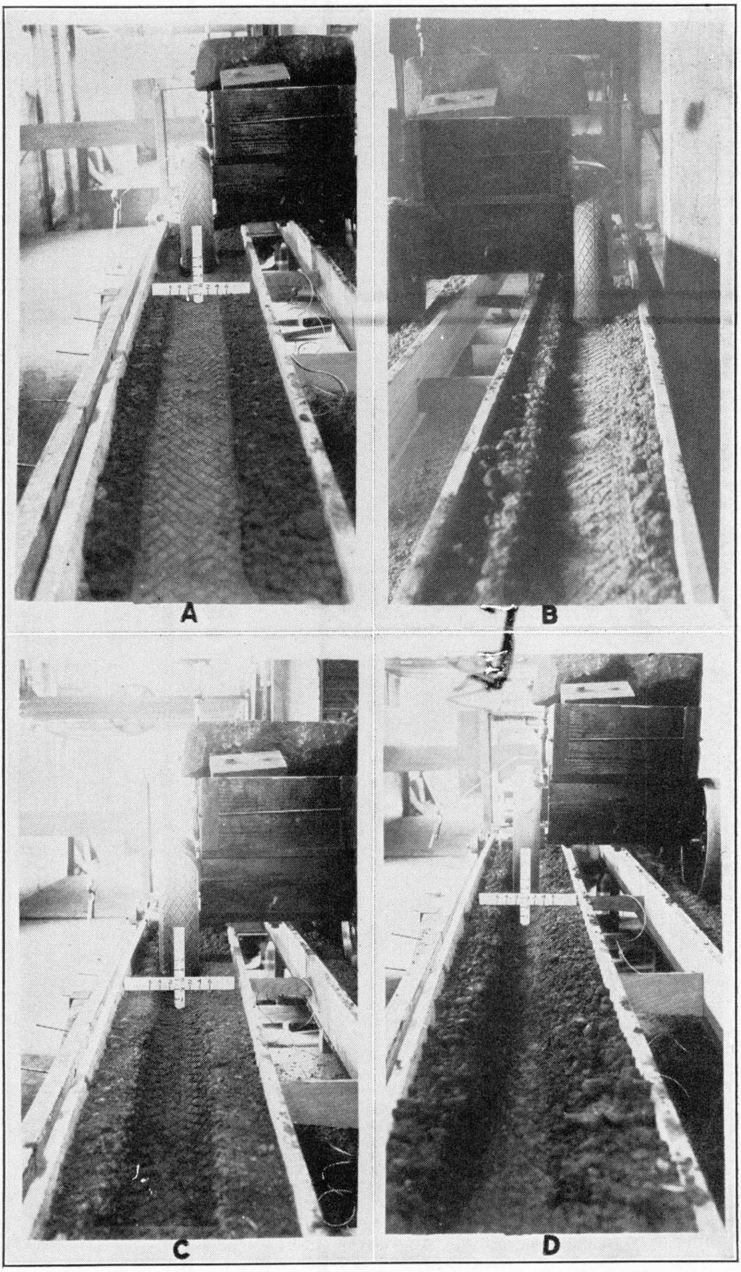


Fig. 16.—Depth and width of wheel tracks in soil

A—Rubber-tired—10 lb. air pressure
B—Rubber-tired—30 lb. air pressure
C—Rubber-tired—50 lb. air pressure
D—Steel wheel — 3-inch rim

TABLE 9.—Draft Tests on Cinder Roads

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Low-pressure....	31	7.50	30	Plain roller	1275	....	1275	2½	9.5
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	2½	21.1
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	2½	38.0
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	2½	61.1
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	10	20.5
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	10	35.5
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	10	58.5
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	20	106.3
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	20	144.7
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	20	175.2
High-pressure...	30	5.00	60	Plain roller	1463	....	1463	2½	18.1
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	2½	36.7
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	2½	56.0
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	2½	75.2
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	10	38.1
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	10	52.1
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	10	69.3
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	20	95.4
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	20	143.9
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	20	171.9
Solid-cushion	30	6.00	......	Plain roller	1623	....	1623	2½	20.5
Solid-cushion	30	6.00	......	Plain roller	1623	2000	3623	2½	47.9
Solid-cushion	30	6.00	......	Plain roller	1623	3500	5123	2½	71.2
Solid-cushion	30	6.00	......	Plain roller	1623	5000	6623	2½	108.5
Solid-cushion	30	6.00	......	Plain roller	1623	2000	3623	10	47.3
Solid-cushion	30	6.00	......	Plain roller	1623	3500	5123	10	67.1
Solid-cushion	30	6.00	......	Plain roller	1623	5000	6623	10	90.1
Solid-cushion	30	6.00	......	Plain roller	1623	2000	3623	20	132.7
Solid-cushion	30	6.00	......	Plain roller	1623	3500	5123	20	192.8
Solid-cushion	30	6.00	......	Plain roller	1623	5000	6623	20	227.6
Steel............	28 and 34	5.00	......	Plain roller	1325	....	1325	2½	35.5
Steel............	28 and 34	5.00	......	Plain roller	1325	2000	3325	2½	90.8
Steel............	28 and 34	5.00	......	Plain roller	1325	3500	4825	2½	136.9
Steel............	28 and 34	5.00	......	Plain roller	1325	5000	6325	2½	174.7
Steel............	28 and 34	5.00	......	Plain roller	1325	2000	3325	5	91.6
Steel............	28 and 34	5.00	......	Plain roller	1325	3500	4825	5	145.8
Steel............	28 and 34	5.00	......	Plain roller	1325	5000	6325	5	187.0

Tests were not made on the steel wheel above a rate of 5 miles per hour, as this seemed to be the maximum speed at which the heavier loads could be operated with safety.

There are other factors to consider relative to road surface which may influence the draft of a wagon or trailer. There may be a slight "cutting-in" action by the wheels on some road surfaces, such as tar-bound macadam, cinders, and unquestionably on dirt roads. However, on gravel roads where loose pebbles or stones of various sizes generally exist, the wheels as they roll are compelled to mount the stones. If the stone is of sufficient compressive strength to resist the weight of the load together with the force required to move the wagon, the load must be raised up over the obstruction. Otherwise, if the stone is not of sufficient compressive strength, it will be crushed and the load will move horizontally. It will require less force to move the load in a horizontal plane if the stone is crushed than if a stone of the same dimensions has sufficiently high compressive strength to withstand the weight of the load. Since the load must be raised vertically, a horizontal force must be applied to overcome the force of gravity. This is exemplified vividly with a load mounted on pneumatic rubber tires.

As the rubber tire contacts an obstruction on the road surface, the load does not rise until the pressure at the contact points of the tire and obstruction is equal to the gross load or force applied at this point. By this time the

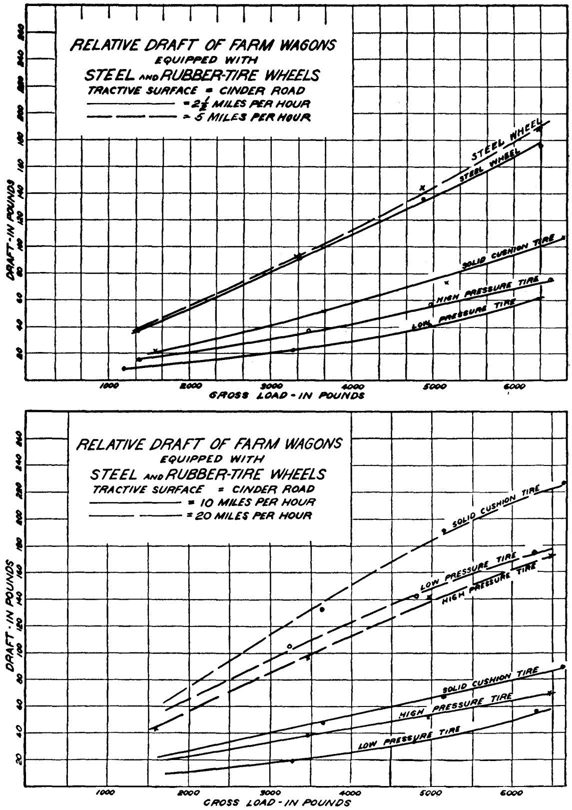

RELATIVE DRAFT OF FARM WAGONS
EQUIPPED WITH
STEEL AND RUBBER-TIRE WHEELS
TRACTIVE SURFACE = CINDER ROAD
= 2½ MILES PER HOUR
= 5 MILES PER HOUR
STEEL WHEEL
STEEL WHEEL
SOLID CUSHION TIRE
HIGH PRESSURE TIRE
LOW PRESSURE TIRE
DRAFT-IN POUNDS
GROSS LOAD-IN POUNDS
RELATIVE DRAFT OF FARM WAGONS
EQUIPPED WITH
STEEL AND RUBBER-TIRE WHEELS
TRACTIVE SURFACE = CINDER ROAD
= 10 MILES PER HOUR
= 20 MILES PER HOUR
SOLID CUSHION TIRE
LOW PRESSURE TIRE
HIGH PRESSURE TIRE
SOLID CUSHION TIRE
HIGH PRESSURE TIRE
LOW PRESSURE TIRE
DRAFT-IN POUNDS
GROSS LOAD-IN POUNDS

Fig. 17

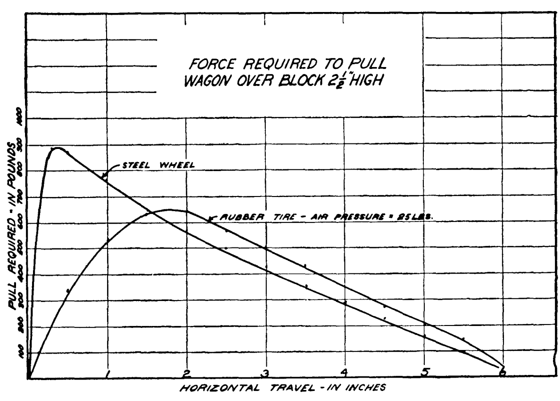

FORCE REQUIRED TO PULL
WAGON OVER BLOCK 2½" HIGH
STEEL WHEEL
RUBBER TIRE - AIR PRESSURE = 25 LBS.
PULL REQUIRED - IN POUNDS
HORIZONTAL TRAVEL - IN INCHES

Fig. 18

obstruction may be well imbedded in the tire and the load progressed considerably in a horizontal plane or forward. If the obstruction is of large dimension, the load of course will be moved slightly in the vertical plane, but, if the obstruction is small, the load may never be moved from a strictly horizontal plane.

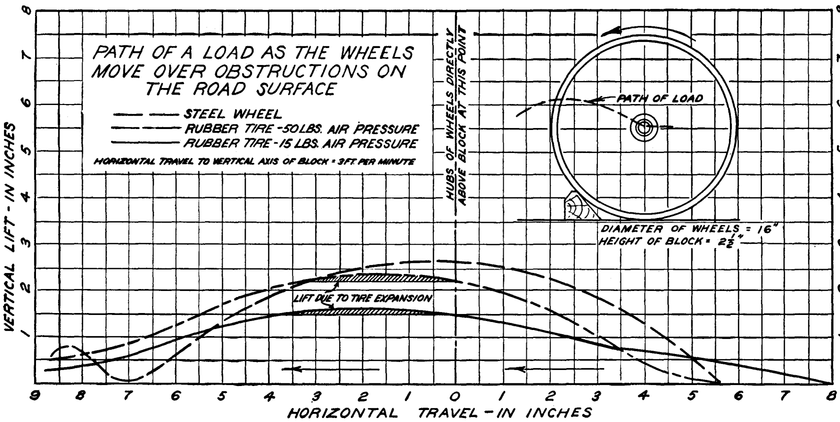


Fig. 19

For a steel wheel to roll over an obstruction, it is necessary to move the load, supported by the wheel, in a vertical plane. In other words, the path of the load on steel wheels will be very irregular, while that of the rubber tire will be smooth and even. This irregularity on the path of the load consumes considerably more draft than one which is smooth and even.

There are also some minor factors which influence the draft of machines equipped with steel and rubber-tired wheels. Probably the most important of these is the rebound factor of the rubber tire. As the rubber tire is moved over an obstruction, the tire is depressed and energy is therefore stored in the tire in the form of increased air pressure. As the hub of the wheel passes the vertical axis or top of the obstruction and starts to come down, the increased air pressure in the tire will force the load forward. A steel wheel with no energy stored up in the form of air pressure will drop to the level more quickly than will the rubber tire. In other words, the increased air pressure in the rubber tire has moved the load further forward. Of course, this form of energy cannot be transferred into feed for the horses or gasoline for the tractor.

GRAVEL ROAD TESTS

According to the Ohio State Highway Department, 52.1 per cent of all state, county, and township roads in Ohio are stone, gravel, and tar-band macadam. Twenty-eight and six-tenths per cent of all roads is earth. Of the former type of roads, approximately 45 per cent falls in the class of township roads, while approximately 92 per cent of the earth roads is township roads. The farmer, therefore, is dependent upon gravel or earth roads for a great deal of his short haulage problems.

TABLE 10.—Draft Tests on Gravel Road

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Low-pressure..	31	7.50	30	Plain roller	1275	....	1275	2½	13.3
Low-pressure..	31	7.50	30	Plain roller	1275	2000	3275	2½	39.9
Low-pressure..	31	7.50	30	Plain roller	1275	3500	4775	2½	48.0
Low-pressure..	31	7.50	30	Plain roller	1275	5000	6275	2½	58.7
Low-pressure..	31	7.50	30	Plain roller	1275	2000	3275	10	42.6
Low-pressure..	31	7.50	30	Plain roller	1275	3500	4775	10	50.2
Low-pressure..	31	7.50	30	Plain roller	1275	5000	6275	10	78.6
High-pressure.	30	5.00	60	Plain roller	1463	....	1463	2½	19.1
High-pressure.	30	5.00	60	Plain roller	1463	2000	3463	2½	50.0
High-pressure.	30	5.00	60	Plain roller	1463	3500	4963	2½	73.4
High-pressure.	30	5.00	60	Plain roller	1463	5000	6463	2½	107.8
High-pressure.	30	5.00	60	Plain roller	1463	2000	3463	10	57.0
High-pressure.	30	5.00	60	Plain roller	1463	3500	4963	10	82.6
High-pressure.	30	5.00	60	Plain roller	1463	5000	6463	10	113.8
Solid-cushion ..	30	6.00	....	Plain roller	1623	....	1623	2½	28.1
Solid-cushion ..	30	6.00	....	Plain roller	1623	2000	3623	2½	62.5
Solid-cushion ..	30	6.00	....	Plain roller	1623	3500	5123	2½	90.2
Solid-cushion ..	30	6.00	....	Plain roller	1623	5000	6623	2½	120.2
Solid-cushion ..	30	6.00	....	Plain roller	1623	2000	3623	10	64.8
Solid-cushion ..	30	6.00	....	Plain roller	1623	3500	5123	10	94.0
Solid-cushion ..	30	6.00	....	Plain roller	1623	5000	6623	10	115.5
Steel...........	28 and 34	5.00	....	Plain roller	1325	....	1325	2½	30.2
Steel...........	28 and 34	5.00	....	Plain roller	1325	2000	3325	2½	105.6
Steel...........	28 and 34	5.00	....	Plain roller	1325	3500	4825	2½	145.7
Steel...........	28 and 34	5.00	....	Plain roller	1325	5000	6325	2½	191.0
Steel...........	28 and 34	5.00	....	Plain roller	1325	....	1325	5	47.9
Steel...........	28 and 34	5.00	....	Plain roller	1325	2000	3325	5	146.3
Steel...........	28 and 34	5.00	....	Plain roller	1325	3500	4825	5	189.2
Steel...........	28 and 34	5.00	....	Plain roller	1325	5000	6325	5	238.9

It was on gravel road that the greatest percentage difference in draft occurred between the steel wheel and the low-pressure tire. At the rate of 2½ miles per hour the low-pressure tire with a 6000-pound gross load required an average draft of 58 pounds. The steel wheel, with the same load and at the same rate of travel, required an average draft of 180 pounds. This great difference in draft is largely due to the fact that the load on the steel wheels must be raised in a vertical plane to a greater degree than that of the low-pressure rubber tire. It was also observed that a large amount of wheel slippage occurred as the steel wheels made an effort to roll over the stones.

The increase in draft of the solid-cushion tire over the low-pressure tire was approximately 52 pounds at the same rate of travel and with the same load. This type of tire does not possess the flexing characteristics of the low-pressure tire. The maximum safe limit in speed for the steel wheel on the gravel road seemed to be approximately 5 miles per hour.

CONCRETE ROAD TESTS

On a smooth concrete road we find an entirely different situation from that occurring on any of the previous tractive surfaces. There is no "cutting-in" action of the wheels and there are practically no obstructions on the road surface of such magnitude as those found on a gravel road. There is an additional factor, however, that seems to enter into the draft of rubber-tired wheels on a smooth surface. From all indications there seems to be a vacuum created between the road surface and the face of the tire as the two come in contact. If this is true then the high-pressure tire and the steel wheel should require less draft than the low-pressure tire on a smooth surface.

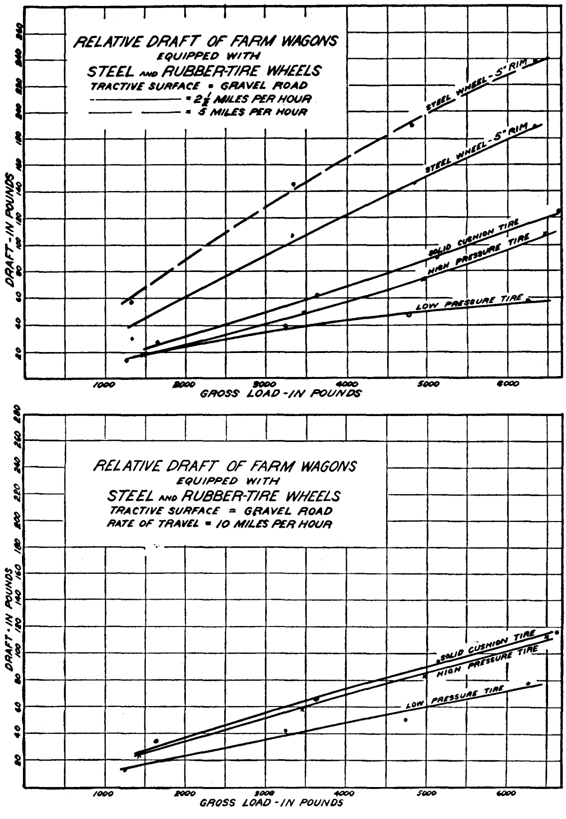
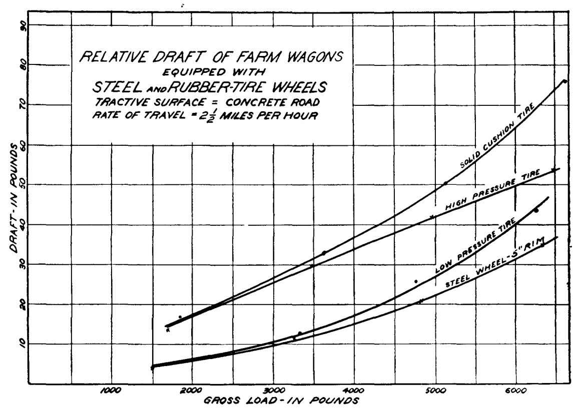

RELATIVE DRAFT OF FARM WAGONS
EQUIPPED WITH
STEEL AND RUBBER-TIRE WHEELS
TRACTIVE SURFACE = GRAVEL ROAD
= 2½ MILES PER HOUR
= 5 MILES PER HOUR
STEEL WHEEL - 5" RIM
STEEL WHEEL - 5" RIM
SOLID CUSHION TIRE
HIGH PRESSURE TIRE
LOW PRESSURE TIRE
DRAFT - IN POUNDS
GROSS LOAD - IN POUNDS
RELATIVE DRAFT OF FARM WAGONS
EQUIPPED WITH
STEEL AND RUBBER-TIRE WHEELS
TRACTIVE SURFACE = GRAVEL ROAD
RATE OF TRAVEL = 10 MILES PER HOUR
SOLID CUSHION TIRE
HIGH PRESSURE TIRE
LOW PRESSURE TIRE
DRAFT - IN POUNDS
GROSS LOAD - IN POUNDS

Fig. 20

TABLE 11.—Draft Tests on Concrete Roads

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Low-pressure....	31	7.50	30	Plain roller	1275	....	1275	2½	4.8
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	2½	11.1
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	2½	26.3
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	2½	43.4
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	10	10.3
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	10	21.6
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	10	24.0
Low-pressure....	31	7.50	30	Plain roller	1275	2000	3275	20	85.1
Low-pressure....	31	7.50	30	Plain roller	1275	3500	4775	20	136.4
Low-pressure....	31	7.50	30	Plain roller	1275	5000	6275	20	159.1
High-pressure...	30	5.00	60	Plain roller	1463	....	1463	2½	13.6
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	2½	29.7
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	2½	42.3
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	2½	54.2
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	10	24.4
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	10	35.5
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	10	57.0
High-pressure...	30	5.00	60	Plain roller	1463	2000	3463	20	92.9
High-pressure...	30	5.00	60	Plain roller	1463	3500	4963	20	126.3
High-pressure...	30	5.00	60	Plain roller	1463	5000	6463	20	134.1
Solid-cushion	30	6.00	......	Plain roller	1623	....	1623	2½	15.2
Solid-cushion	30	6.00	......	Plain roller	1623	2000	3623	2½	33.1
Solid-cushion	30	6.00	......	Plain roller	1623	3500	5123	2½	50.1
Solid-cushion	30	6.00	......	Plain roller	1623	5000	6623	2½	76.7
Solid-cushion	30	6.00	......	Plain roller	1623	2000	3623	10	29.8
Solid-cushion	30	6.00	......	Plain roller	1623	3500	5123	10	40.9
Solid-cushion	30	6.00	......	Plain roller	1623	5000	6623	10	65.5
Solid-cushion	30	6.00	......	Plain roller	1623	2000	3623	20	138.3
Solid-cushion	80	6.00	......	Plain roller	1623	3500	5123	20	186.9
Solid-cushion	30	6.00	......	Plain roller	1623	5000	6623	20	275.5
Steel.............	28 and 34	5.00	......	Plain roller	1325	....	1325	2½	3.0
Steel.............	28 and 34	5.00	......	Plain roller	1325	2000	3325	2½	12.3
Steel.............	28 and 34	5.00	......	Plain roller	1325	3500	4825	2½	20.0
Steel.............	28 and 34	5.00	.....	Plain roller	1325	5000	6325	2½	35.0

The results of these tests show that the steel wheel required less draft than any of the other types of wheels tested. This of course was only at 2½ miles per hour. At 10 miles per hour the low-pressure tire required slightly less draft than the high-pressure tire. At 20 miles per hour the high-pressure tire required the least. At all speeds the solid-cushion tire required the greatest draft.


RELATIVE DRAFT OF FARM WAGONS
EQUIPPED WITH
STEEL AND RUBBER-TIRE WHEELS
TRACTIVE SURFACE = CONCRETE ROAD
RATE OF TRAVEL = 2½ MILES PER HOUR
SOLID CUSHION TIRE
HIGH PRESSURE TIRE
LOW PRESSURE TIRE
STEEL WHEEL-5" RIM
DRAFT - IN POUNDS
GROSS LOAD - IN POUNDS

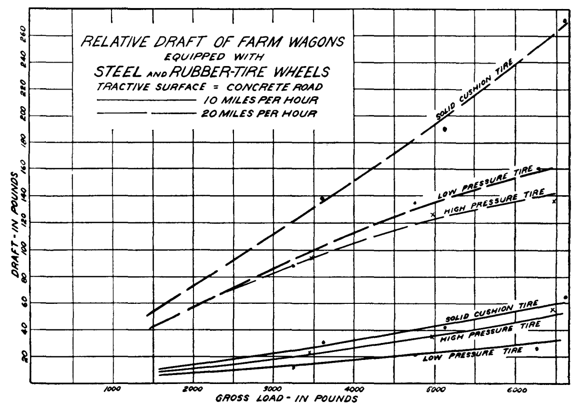

RELATIVE DRAFT OF FARM WAGONS
EQUIPPED WITH
STEEL AND RUBBER-TIRE WHEELS
TRACTIVE SURFACE = CONCRETE ROAD
10 MILES PER HOUR
20 MILES PER HOUR
SOLID CUSHION TIRE
LOW PRESSURE TIRE
HIGH PRESSURE TIRE
SOLID CUSHION TIRE
HIGH PRESSURE TIRE
LOW PRESSURE TIRE
DRAFT - IN POUNDS
GROSS LOAD - IN POUNDS

Fig. 21

EFFECT OF WIDTH OF RIM OF STEEL WHEELS ON THE DRAFT OF A WAGON

CINDER ROAD—CULTIVATED SOIL—MEADOW

Several tests were run to determine the effect of width of rim of steel wheels on the draft of a wagon. The wheels were all of the same diameter and all equipped with plain roller bearings. The rim widths were 4, 5, and 6 inches. Unfortunately, narrower rims, having a corresponding wheel diameter, could not be obtained.

The tests were run on cultivated soil, meadow, and cinder road. All of these tractive surfaces were in a very dry condition. A wet condition of these surfaces would probably alter the results considerably.

TABLE 12.—Cinder Road Test

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Steel	28 and 34	4	....	Plain roller	1271	2000	3271	5	102.6
Steel	28 and 34	5	....	Plain roller	1325	2000	3325	5	91.6
Steel	28 and 34	6	....	Plain roller	1365	2000	3365	5	105.7
Steel	28 and 34	4	....	Plain roller	1271	3500	4771	5	147.1
Steel	28 and 34	5	....	Plain roller	1325	3500	4825	5	145.8
Steel	28 and 34	6	....	Plain roller	1365	3500	4865	5	159.0
Steel	28 and 34	4	....	Plain roller	1271	5000	6271	5	191.0
Steel	28 and 34	5	....	Plain roller	1325	5000	6325	5	185.0
Steel	28 and 34	6	....	Plain roller	1365	5000	6365	5	195.4

TABLE 13.—Cultivated Soil Tests

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Steel	28 and 34	4	......	Plain roller	1271	2000	3271	2½	728.0
Steel	28 and 34	5	......	Plain roller	1325	2000	3325	2½	731.5
Steel	28 and 34	6	......	Plain roller	1365	2000	3365	2½	656.5
Steel	28 and 34	4	......	Plain roller	1271	3500	4771	2½	1070.5
Steel	28 and 34	5	......	Plain roller	1325	3500	4825	2½	1031.0
Steel	28 and 34	6	......	Plain roller	1365	3500	4865	2½	988.5
Steel	28 and 34	4	......	Plain roller	1271	5000	6271	2½	1552.5
Steel	28 and 34	5	......	Plain roller	1325	5000	6325	2½	1175.0
Steel	28 and 34	6	......	Plain roller	1365	5000	6365	2½	1295.5
Steel	28 and 34	4	......	Plain roller	1271	2000	3271	3¼	742.0
Steel	28 and 34	5	......	Plain roller	1325	2000	3325	3¼	686.0
Steel	28 and 34	6	......	Plain roller	1365	2000	3365	3¼	642.5
Steel	28 and 34	4	......	Plain roller	1271	3500	4771	3¼	1149.0
Steel	28 and 34	5	......	Plain roller	1325	3500	4825	3¼	911.0
Steel	28 and 34	6	......	Plain roller	1365	3500	4865	3¼	900.0
Steel	28 and 34	4	......	Plain roller	1271	5000	6271	3¼	1438.0
Steel	28 and 34	5	......	Plain roller	1325	5000	6325	3¼	1188.0
Steel	28 and 34	6	......	Plain roller	1365	5000	6365	3¼	1298.5
Steel	28 and 34	5	......	Plain roller	....	....	1325	2½	205.0
Steel	28 and 34	5	......	Plain roller	....	....	1325	3¼	240.3

TABLE 14.—Meadow

Wheels				Bearing	Load			Miles per hour	Pounds pull gross load
Type	Diameter	Width of tire	Inflation		Tare	Net	Gross		
	In.	*In.*	*Lb.*						
Steel.........	28 and 34	4	....	Plain roller	1271	2000	3271	2½	189.3
Steel.........	28 and 34	5	....	Plain roller	1325	2000	3325	2½	119.6
Steel.........	28 and 34	6	....	Plain roller	1365	2000	3365	2½	168.8
Steel.........	28 and 34	4	....	Plain roller	1271	3500	4771	2½	337.0
Steel.........	28 and 34	5	....	Plain roller	1325	3500	4825	2½	232.7
Steel.........	28 and 34	6	....	Plain roller	1365	3500	4865	2½	274.0
Steel.........	28 and 34	4	....	Plain roller	1271	5000	6271	2½	551.1
Steel.........	28 and 34	5	....	Plain roller	1325	5000	6325	2½	418.3
Steel.........	28 and 34	6	....	Plain roller	1365	5000	6365	2½	393.3
Steel.........	28 and 34	4	....	Plain roller	1271	2000	3271	3¼	185.0
Steel.........	28 and 34	5	....	Plain roller	1325	2000	3325	3¼	133.9
Steel.........	28 and 34	6	....	Plain roller	1365	2000	3365	3¼	156.1
Steel.........	28 and 34	4	....	Plain roller	1271	3500	4771	3¼	320.8
Steel.........	28 and 34	5	....	Plain roller	1325	3500	4825	3¼	189.1
Steel.........	28 and 34	6	....	Plain roller	1365	3500	4865	3¼	251.9
Steel.........	28 and 34	4	....	Plain roller	1271	5000	6271	3¼	510.5
Steel.........	28 and 34	5	....	Plain roller	1325	5000	6325	3¼	347.5
Steel.........	28 and 34	6	....	Plain roller	1365	5000	6365	3¼	364.7

Throughout all of the tests the 4-inch rim required the greatest draft. During the series of tests on cultivated soil it was noticed that the track made by the 4-inch rims of the front truck filled in nearly level with soil from the sides of the wheel track. This necessitated the rear wheels cutting an additional track, which undoubtedly added considerably to the draft of the wagon. No trouble of a similar nature was had with either the 5- or 6-inch rims.

Table 15 shows the relative depths of track made by the various widths of rim in cultivated soil. The net load was 5000 pounds and the rate of travel 2½ miles per hour.

TABLE 15.—Depth of Wheel Tracks Made by 4-, 5-, and 6-inch Rims

Rim width	Depth of track		Total depth
	Front	Rear	
In.	*In.*	*In.*	*In.*
4..	3¼	½	3¾
5..	2¾	½	3¼
6..	2½	½	3

On all of the tractive surfaces there was little difference in draft between the 5- and 6-inch rims. At times, especially at the heavier loads, the 5-inch rim seemed to require less draft than the 6-inch rim.

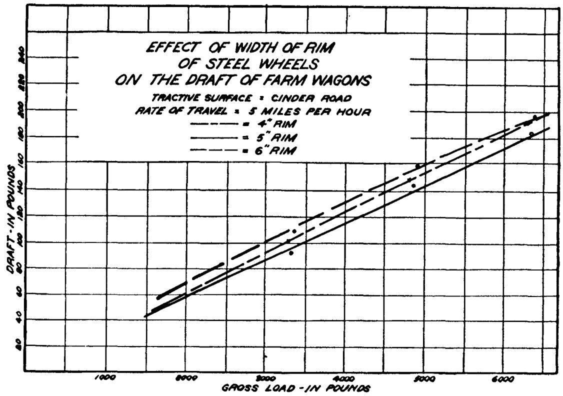

EFFECT OF WIDTH OF RIM
OF STEEL WHEELS
ON THE DRAFT OF FARM WAGONS
TRACTIVE SURFACE = CINDER ROAD
RATE OF TRAVEL = 5 MILES PER HOUR
= 4" RIM
= 5" RIM
= 6" RIM
DRAFT-IN POUNDS
1000
2000
3000
4000
5000
6000
GROSS LOAD-IN POUNDS

Fig. 22

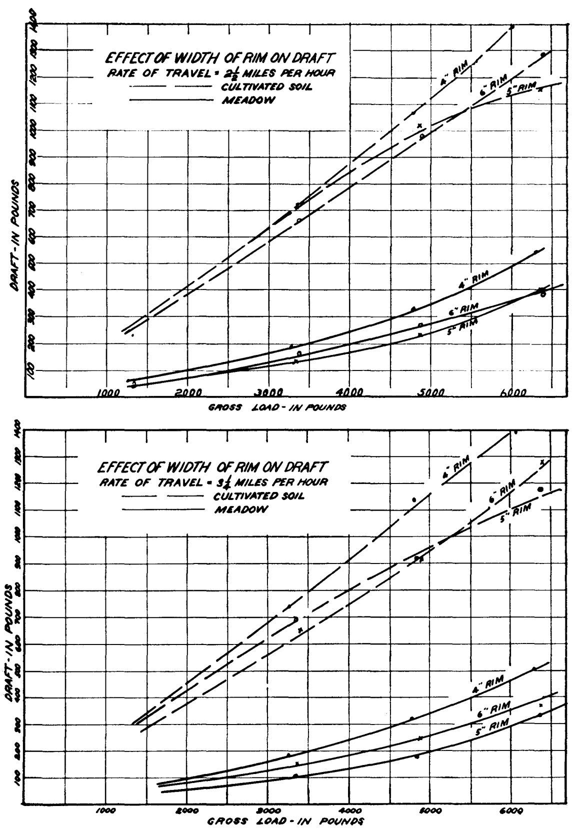

EFFECT OF WIDTH OF RIM ON DRAFT
RATE OF TRAVEL = 2½ MILES PER HOUR
CULTIVATED SOIL
MEADOW
4" RIM
6" RIM
5" RIM
DRAFT-IN POUNDS
1000
2000
3000
4000
5000
6000
GROSS LOAD-IN POUNDS
EFFECT OF WIDTH OF RIM ON DRAFT
RATE OF TRAVEL = 3¼ MILES PER HOUR
CULTIVATED SOIL
MEADOW
4" RIM
6" RIM
5" RIM
DRAFT-IN POUNDS
1000
2000
3000
4000
5000
6000
GROSS LOAD-IN POUNDS

Fig. 23

TYPES OF WHEEL BEARINGS

A number of tests was run on a cinder road to determine the effect of the type of bearing on the draft of the wagon. The bearings used were the taper roller, plain roller, skein in wood wheel, skein in steel, and the plain bearing. The plain roller bearing is one in which no outer or inner race is used, but instead the rollers contact directly on the axle and the bore of the hub.

There was some variation in the width of rims and diameter of wheels but from previous tests on cinder roads these two factors were not of much importance. The results of these tests, therefore, can be considered as being fairly representative and comparable. Figure 24 indicates that at both 2½ and 5 miles per hour the taper roller bearing required the least draft, while the steel wheel with the skein type of bearing required the most.

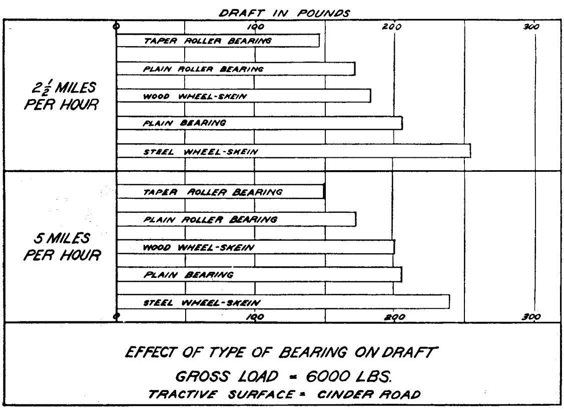


Fig. 24

EFFECT OF SPEED ON THE DRAFT OF FARM WAGONS

The speed or rate of travel seems to have an influence on the draft of the wagon. The least draft occurred at approximately 8 miles per hour. Above this rate the draft increased very rapidly. The tests were made on the cinder road and the speeds varied from one to 20 miles per hour. The tests were recorded over a 100-foot stretch with 200 feet allowed for acceleration. The wheels were all equipped with plain roller bearings.

CORN PICKER TESTS

Two series of tests were made on a corn picker—draft tests and general observation tests. For the draft tests the picker was equipped with both steel and rubber-tired wheels.

The diameters of the wheels were as follows:

Steel — 46 inches in diameter
Steel — 40 inches in diameter
Rubber— 42 inches in diameter

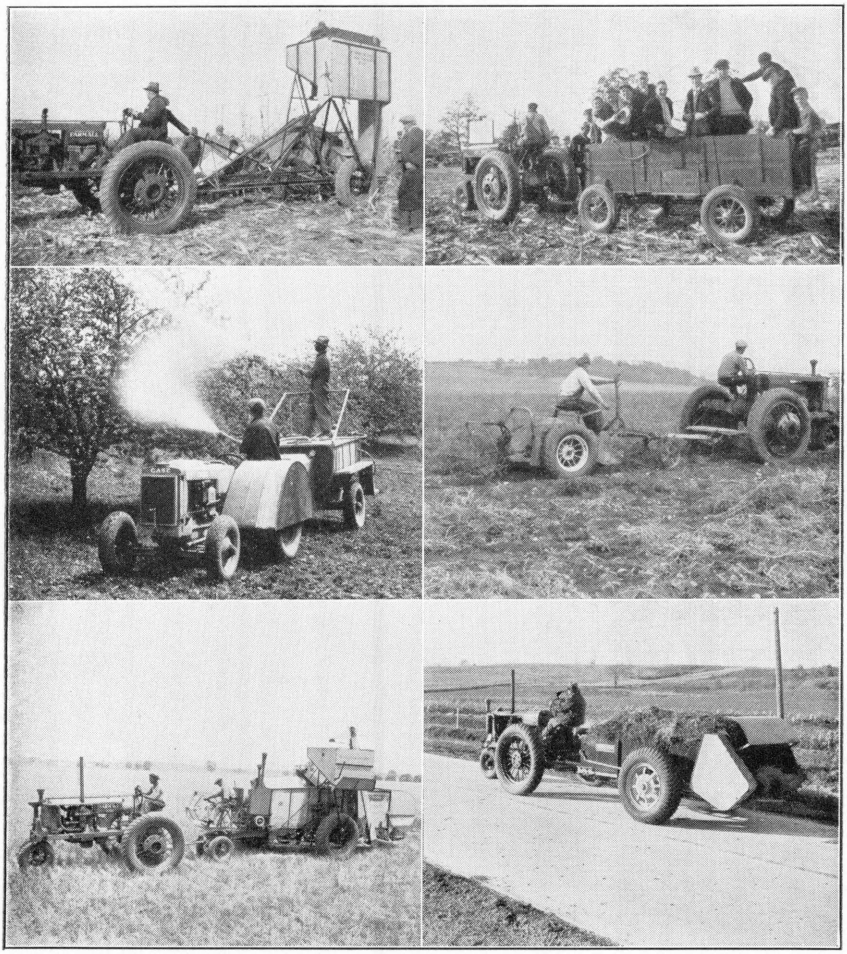


Fig. 25.—A number of farm machines very well adapted to the use of rubber-tired equipment

From Figure 26 it is readily seen that the picker with the rubber-tired equipment requires much less draft than one equipped with either of the steel wheels and that the 46-inch wheel offers less rolling resistance than the 40-inch wheel. These results are similar to those on the draft of wagons. The same relative results are obtained with the picker on plowed ground.

These tests were made when the ground was very dry. Should the tests have been made when the ground was in a more moist condition, undoubtedly the difference in draft would have been much greater.

The general observation tests were made on a single-row picker equipped with rubber tires. The work was done at a time when the ground was wet. It was observed that the picker operated with much less vibration or jolting. The tires did not pick up surface trash to any great extent, while the steel wheels filled up rapidly.

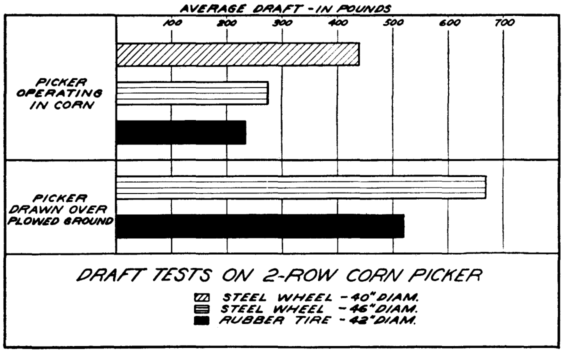


Fig. 26

SUMMARY

A tractor equipped with low-pressure pneumatic tires has a lower rolling resistance than one equipped with steel wheels and lugs.

The fuel consumption of a tractor equipped with low-pressure pneumatic tires is less than that of one equipped with steel wheels and lugs at the same relative draw-bar pull.

Under most conditions rubber-tired equipment on tractors is very satisfactory for plowing or for other farm operations.

Rubber tires on tractors are ineffective where moist barnyard manure has been spread over the ground.

Under favorable conditions rubber-tired equipment will transmit a greater draw-bar horsepower than steel-wheel equipment in second or third gears.

Rubber-tired equipment makes it possible to use the tractor for many more jobs which could not be done with steel-wheel equipment.

The tread of rubber tires does not pick or fill up with surface trash like steel wheels and lugs.

Rubber-tired equipment permits higher speeds which generally result in greater fuel economy.

Less dust is stirred up by the rubber tires on dry surfaces.

With 1349 hours of use, there has been no evidence of excessive wear on the tires. During that time only two punctures were experienced.

Under most conditions a tractor equipped with rubber tires is more comfortable for the operator to ride. The elimination of severe shocks and impacts should give the tractor a much longer life.

On all rough and soft tractive surfaces the low-pressure rubber tire on wagons required the least draft.

On smooth, hard surfaces, the steel wheel required the least draft.

On cultivated soil or meadow the rubber tire will not "cut in" as deeply as the steel wheel.

Rubber tires will not damage meadows as badly as will steel wheels.

The width of rim of steel wheels is a factor in cultivated soil, with the wider rim usually having the advantage in draft. A narrow wheel track usually fills in after the wheel has cut through, making it necessary for the rear wheels to cut a new track.

The roller type of bearing required much less draft than the plain or skein type of bearing.

On a cinder road the least draft was recorded at a speed of approximately 8 miles per hour for rubber-tired equipment on wagons. Above that speed the draft increased rapidly.

A corn picker equipped with rubber tires required much less draft than the same picker equipped with steel wheels. Much less surface trash was picked up by the rubber tires.